THE RELATIVE EFFICIENCY OF DIFFERENT FORMS OF NITROGEN AND POTASSIUM IN POTATO PRODUCTION ON THE EASTERN SHORE OF MARYLAND.

by

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Introduction.

The use of various nitrogenous and potassium fertilizer materials in the production of early potatoes and sweet potatoes on the Eastern Shore of Maryland, presents some very important fertility problems. Practically all the land used for potato production, in this section of Maryland, is so low in the so-called essential plant food elements, nitrogen, phosphorus, and potassium, that large amounts of complete fertilizer are usually applied annually in order to grow satisfactory early crops of good quality. On account of the sandy nature of the predominating soil types, in wet seasons it is more than likely that a considerable amount of the fertilizer applied, especially that portion in the form of nitrates is lost by leaching. Hence, the fertility problem is two-fold, namely, that of providing an adequate supply of soluble nitrate material for rapid early growth, and that of maintaining a sufficient supply throughout the growing season. To meet this two-fold requirement, the nitrogen in the fertilizer mixture is generally supplied from several sources. However, mixtures of nitrate materials may not be necessary as certain of the synthetic nitrogen materials, especially urea, have given promise of satisfying the nitrogen requirements when used alone in the fertilizer mixture.

Not only are fertilizers containing large amounts of nitrogen usually required, but also some mixtures containing relatively large quantities of potash as well. Scarcely a truck crop can be grown on these soils that will not show some favorable response from potash applications. In this respect the comparative effect of low and high grade potash materials is important, especially where sweet potatoes are grown, since this is a crop requiring relatively large amounts of potash. Moreover, the importance of the entire subject of the utilization of both potash and nitrogen materials for potato production is further augmented by the small number of fertilizer analyses used, making still more important the selection of the most suitable materials for each crop.

Some idea of the economic importance of fertilizing the potato crop in Maryland may be gained from a study of the crop statistics as reported by the U. S. Department of Agriculture (49). During the 1927 season in Maryland, 15,400 acres were planted to early potatoes and this acreage produced a total of 2,155,000 bushels at an estimated value of $2,586,000. During the same year, 11,000 acres were planted to sweet potatoes, producing 1,500,000 bushels at an estimated value of $1,109,000. On the basis of an 1800-pound application per acre, the fertilizer used for early potatoes would amount to nearly 14,000 tons but for sweet potatoes, the amount would be somewhat less owing to the relatively small application of fertilizer used for growing this crop.

The magnitude and importance of potato production, not only in Maryland but in adjoining States, has stimulated field experimental work, particularly from the nutrition standpoint. This work may be conveniently divided into three rather general classes; limiting factor experiments, using single applications of fertilizer materials; experiments including combinations of different types of fertilizer materials; and those experiments of a more or less economical nature using different rates of fertilizer applications and involving the law of diminishing returns.

The present work may be classified under the last two divisions. Different kinds of nitrogen and potassium materials were used alone and in combinations but always in a complete fertilizer, except in the case of the check plots. Studies on the rate of fertilizer application and the effect of increasing potassium in the mixture were also included in the investigation. Supplementing the fertilizer studies, a green manure cover crop experiment was conducted to determine the effects of this practice, in conserving the fertilizer not utilized by the potato crop and in ultimately increasing the fertility of the soil.

Review of Literature

1. Experiments with Fertilizers for Early Potatoes.

In view of the long continued use of the potato in the human diet, it is quite natural to find reports of fertilizer experiments on this crop reported in early literature. However, as a rule, the results of these earlier investigations have been for the most part, rather indefinitely reported. For this reason the following review of early potato investigations will be confined to some of the more recent work on the subject.

Whitney (54), in summarizing the results of potato fertilizer investigations conducted in twenty-three states, on a large number of soils and extending over a period of years, concluded that the actual increases in bushels of potatoes were larger with two or three fertilizer materials, mixed, than with single substances.

Truog, Harper, Magistad, Parker and Sykora (47) compared the growth of potatoes in sand cultures supplied with complete nutrient solutions, with the nitrogen supplied from two mineral sources. They obtained the best growth with nitrate of soda and only poor growth with sulphate of ammonia. A mixture of the two materials, however, gave a fairly good growth. Attention was called to the importance of supplying nitrogen in several forms for field applications of fertilizer. It was pointed out that this practice would avoid a toxic effect from ammonical nitrogen, excess loss by leaching, and delay of early growth when only organics are used.

White (53), on the other hand, concluded that the poorest yields of potatoes were produced where nitrate of soda was used at the rate of 2000 pounds per acre. This conclusion was based on the results of tests conducted at College Park and Ridgely, Maryland. Contrary to these results, Lipman and Blair (27) found that nitrate of soda gave larger yields of potatoes than equivalent amounts of sulphate of ammonia, fish or tankage.

Noer (30) compared activated sewage sludge with various organic and inorganic fertilizer materials as sources of ammonia in a complete potato fertilizer, and concluded that activated sewage sludge was a satisfactory source of nitrogen when used in this manner. It was also pointed out that activated sewage sludge exerted a favorable influence on the mechanical condition of the mixed fertilizers.

Russell (36) reported the results obtained with potatoes in a comparison of the newer nitrogenous fertilizers in Great Britain. He concluded that urea was of the same order of value as a fertilizer as nitrate of soda and sulphate of ammonia. It was pointed out that the use of urea had several distinct advantages; does not wash out of the soil, does not puddle soils as does nitrate of soda, does not remove lime as does sulphate of ammonia, and makes a fertilizer mixture with good mechanical condition. Brown (4), conducted extensive experiments in various sections of the United States and compared the results obtained with organic and inorganic forms of nitrogen in the fertilizer mixture. Among other things he found that sulphate of ammonia gave better yields of potatoes than nitrate of soda in 9 out of 10 cases. When one-half of the ammonia was supplied from an organic source, there was an increase of 3.6 bushels obtained over the yield from the treatment containing only inorganic ammonia. In an earlier publication, Brown (5), summarized the results of some experiments with various nitrogen materials used in a complete fertilizer for potatoes conducted in New York, Virginia, and Maine. He found that urea compared very favorably with nitrate of soda and sulphate of ammonia as a source of nitrogen for potatoes. In the same paper, were reported the results of 16 distinct experiments on different soil types over a period of years with three domestic potash materials. Muriate of potash, sulphate of potash, and Nebraska salts were used in complete mixtures containing 3, 5, and 7% potash, 4% ammonia, and 8% phosphoric acid in each case. Very uniform yields of potatoes were obtained from all the treatments but muriate of potash gave uniformly better yields than the other two potash materials. The following table showing the results obtained by Brown is given, since the comparative effects of muriate and sulphate of potash obtained corresponds closely with the results of the present potash studies that will be presented later.

	3%	5%	7%
Muriate of potash	234.7	240.4	245.1
Sulphate of potash	230.3	234.3	231.4
Nebraska salts	229.6	232.9	225.5

Starch determinations were made on samples of potatoes taken from the potash and no-potash plots. The results showed that muriate did not lower the starch content of potatoes in comparison with sulphate of potash. Furthermore, it is rather significant that no increase in the starch content was found for the potatoes from the muriate plot in comparison with those taken from the no-potash plot. Zimmerly (56), has shown that in Eastern Virginia, muriate of potash gave better yields of potatoes than sulphate of potash. These results were obtained over a period of three years when 160 pounds of potash were applied per acre each year. However, when this amount of potash was doubled the increases for muriate were not uniform and the results indicated a slight toxic effect.

The work of Pate and Skinner (31) gave some evidence that ammonia and potash had more influence on the yields of potatoes than phosphoric acid. However, the results as a whole showed that the best yields were obtained where a fertilizer containing nearly equal proportions of ammonia, phosphoric acid, and potash was used. The yields of potatoes were decreased when potash was withheld from the fertilizer mixture. Woods (55), studying the effects of omitting potash from the fertilizer used for potatoes in Maine, obtained a profitable increase in yields when 1500 pounds of fertilizer containing 3% potash was applied. He also reported a beneficial effect on yields of potatoes when 300 pounds of sodium chloride were used per acre.

The average yields of potatoes obtained by Bergh (3) on a sandy loam soil with Irish Cobbler and Green Mountain varieties, show an increase of 60 bushels of marketable potatoes for the potash plots over the yields from the no-potash plots. Increases for the potash applications were consistent where no stable manure had been applied. In other words, stable manure evidently helped to offset the effect of a fertilizer unbalanced with respect to potash.

Contrary to the results obtained by many investigators, Cooper and Rapp (8) found no beneficial effect on yields of potatoes from the use of potash in the fertilizer mixture. On the basis of returns per pound of fertilizer used, they ranked the fertilizer ingredients as follows: nitrogen, 2.08 bushels of potatoes; phosphoric acid, 1.605 bushels of potatoes; and potash, 1.23 bushels of potatoes. Wallace (51) found that potash manure salts did not give as high yields of potatoes as muriate, or sulphate of potash. He also noted that the leaves of the plants on all no-potash plots had a distinctly deeper green color than the leaves of the plants on the potash-treated plots. In this connection, Schreiner (39) made a rather complete study of the symptoms associated with potash hunger of the potato plant. These he observed may be characterized by dark green foliage, convex wrinkled leaf, drooping, and later exhibiting a bronzing effect. These symptoms were observed to be more marked in the potato fields on the sandy soils of the Atlantic Coastal Plain Region. Potash hunger symptoms, as exhibited by the potato plant, are very characteristic and offer a fairly reliable guide in the fertilization of this crop.

Although no particular mention has been made of the effects of phosphoric acid on the potato crop, it is conceded that phosphoric acid is an essential ingredient of potato fertilizers in a large majority of cases. However, it was decided to confine the present discussion to the effects of nitrogen and potash in accordance with the experimental work that will be described later.

2. Experiments with Fertilizers for Sweet Potatoes.

It is significant that a large portion of the experimental work on fertilizers for sweet potatoes has been concerned chiefly with the effects produced by nitrogen and potassium. That these two elements are important in sweet potato production was brought out rather strikingly by Keitt (21), in a chemical analysis of fourteen different varieties of sweet potatoes. His results showed that the following amounts of nitrogen, phosphoric acid, and potash were removed from the soil by the sweet potato storage roots:

Nitrogen	0.348%	to 0.184%
Phosphoric Acid.	0.0893%	to 0.0435%
Potash	0.684%	to 0.336%

It would seem from these results that nitrogen and potash should be expected to play a more important part than phosphorus in the fertilization of sweet potatoes. Consequently, various nitrogen and potassium materials have been used more than phosphorus materials for fertilizer studies with sweet potatoes. Scott (40), found as a result of five year's study on fertilizers for sweet potatoes, that both sulphate of ammonia and dried blood are suitable sources of nitrogen for this crop. He also found that fertilizers containing potash were needed in order to produce a satisfactory yield of potatoes. From a comparison of muriate and sulphate of potash he found that the muriate plot out-yielded the sulphate plot by 18.2 bushels of potatoes. It is rather significant that there were no differences noted in the extent of vine growth on any of the plots.

Stuckey (45), summarized the results of 12 year's experimental work on a comparison of single applications of mineral fertilizer materials, and a complete fertilizer mixture for sweet potatoes. With respect to the yields of potatoes obtained, the fertilizer treatments may be ranked as follows: first, complete; second, sulphate of potash; third, acid phosphate, fourth, nitrate of soda; and fifth, check (no fertilizer). It was stated that yields of potatoes obtained from the various treatments, in comparison with those obtained from the check plots, did not warrant the use of fertilizers in large amounts.

In an earlier publication, Stuckey (44) reported the results of some extensive studies on the effects of different fertilizer materials on the weight and chemical composition of the sweet potato vines produced. It was concluded that high nitrogen applications had a tendency to increase the weight of vines but did not materially effect their chemical composition. Chemical determinations made on the potatoes also showed no significant variations for the different treatments. Nitrate of soda used alone produced the smallest potatoes, whereas a complete fertilizer, and likewise a sulphate of potash treatment, had a tendency to increase the size. Neither the percentage of starch nor the percentage of sugar showed significant differences in the potatoes produced, where a 2-12-2 and where a 3-12-4 fertilizer was applied each year over a period of two years. It was concluded from a comparison of the weight of vines produced and the yield of potatoes, that the size of the crop cannot be forecast from the extent of the vine growth.

Contrary to the results obtained by Stuckey (44), it is commonly thought that there is a relation between the growth of sweet potato vines and the yield of sweet potatoes. For lack of experimental evidence, much doubt exists concerning the effect of various fertilizer materials on the production of sweet potato vines and storage roots. However, more is known about the effect of fertilizer materials on the shape of sweet potatoes. Results of field experiments have been obtained which indicate that certain fertilizer ingredients tend to produce long narrow sweet potatoes and others tend to produce short thick ones. Whether this effect is directly associated with the manufacture and translocation of carbohydrate materials for root storage, or merely the resultant of a change in the relationship between vine growth and root storage, is not known. In respect to the effects of fertilizers on the shape of sweet potatoes, the work of Schermerhorn (37) is of particular interest. He found that increasing amounts of nitrogen in the fertilizer mixture, produced a relatively long potato, whereas increasing amounts of potash, produced a potato of the "chunk" type. These results are particularly significant from an economic standpoint, since the market at the present time demands a "chunk" type of sweet potato. The same author obtained increased yields of potatoes when complete fertilizers containing as high as 8% potash were used. A complete fertilizer containing this amount of potash produced an increased yield of 99.5 bushels of potatoes, over that obtained from the no-potash treatment.

Several attempts have been made to determine the relation between the starch and sugar content of the sweet potatoes and the kind of fertilizer used, but the results so far have been unsatisfactory. However, Quinn (35), in 1925, found a definite correlation between the amount of potash used as fertilizer and the percentage of carbohydrates in the potatoes produced. It was claimed that potash applications not only increased the percentage of starch and sugars, but also produced a larger yield of marketable potatoes. It is interesting to note that Quinn also observed that the vine growth was unaffected by the fertilizer treatments.

Johnson, Zimmerly, and Geise (20) studied the relative effects of several sodium and potassium salts, when used for top-dressing sweet potatoes. It was found that the complete fertilizer plots which were top-dressed with sodium chloride produced an average increase of 42.7 bushels of marketable potatoes, over the yield obtained from the same treatment without the sodium chloride top-dressing. This increase was consistent for both the late and early harvest of the sweet potatoes. It was pointed out that all of the treatments containing chloride salts, compared very favorably with those containing sulphates.

Geise (14), as a result of several year's experimental work, chiefly with single applications of fertilizer materials, concluded that a complete fertilizer was essential for the production of sweet potatoes. However, he found that responses in yields from potassium applications were, as a rule, greater than the responses from nitrogen or phosphoric acid applications. The results of an experiment for one year, showed an increase of 40 bushels of potatoes from a 2-8-10 fertilizer treatment, over the yield obtained from a 2-8-8 fertilizer. Likewise, a 3-8-10 fertilizer treatment outyielded a 3-8-8 fertilizer treatment by 23 bushels of potatoes.

As strong as the case may seem for the beneficial effects of potash treatments on sweet potatoes, yet results have been reported where potash applications have not produced increased yields. Hotchkiss (18), found from a comparison of several fertilizer materials used alone and in different combinations, that sulphate of potash gave the lowest yield of any treatment, It was pointed out that apparently potash was not a limiting factor in the soil used for the experiments. Knapp (22) also reported no increases in yields of sweet potatoes where potash applications were made.

Summarizing the experimental work done with fertilizers for sweet potatoes, it seems quite evident that potash and nitrogen in one form or another are needed for sweet potato production on the majority of soils. Exactly which form of nitrogen and potash is best, is still a matter to be determined by experiment, probably for each soil condition.

3. Adsorption Experiments with Different Potassium Materials.

Since fertilizers relatively high in potash are quite generally used for potato production, the importance of determining the adsorption power of the soil with respect to the potassium in the different materials used, and the availability after adsorption, is at once apparent.

For almost a century, investigators have known that soils in general possess the power to decrease the concentration of salt solutions with which they are brought in contact. As early as the latter part of the Eighteenth Century much work had been done on the subject and considerable data had been accumulated. This earlier work has been compiled and reviewed in detail by Patten and Waggaman (32). Of the early investigations, the classical work of Way, Frank, Treutler, and Peters, is perhaps the most outstanding. Way (52), as early as 1850 found an excess of bases held by sand treated with salts. Frank (11), in one of his percolation experiments, found 95.5% of the potassium of a 0.1% solution of potassium chloride retained by an 18 inch column of soil. Treutler (46), found that additions of sodium chloride reduced the amount of potassium retained by soils treated with solutions of potassium chloride, thus confirming the earlier work of Frank (11). However, Fisher (10), in a more recent publication, presented the work of Lemberg which shows a replacement of sodium by potassium in soils. It was pointed out that under similar conditions, potassium will replace sodium, as might be suggested by the retention of large amounts of potassium by soil, in comparison to sodium. Furthermore, the presence of sodium chloride rather than potassium chloride in the ocean is suggestive of the relative amounts of these two salts that may be held by soils.

Patten and Waggaman (32) recalculated the results obtained by Peters (34) on the removal of potassium chloride from solution by soil. The recalculated results showed that the removal of potassium was nearly twice as great from a weak solution , as was obtained when a solution twenty times stronger was used.

Schreiner and Failyer (38) percolated a potassium chloride solution containing 200 p.p.m. of potassium through a short column of sandy loam soil at the rate of 50 c.c. in 24 hours. The first 200 c.c. of percolate was reduced to 96 p.p.m. of potassium and thereafter the amount of potassium in the percolate steadily increased. It was concluded that the potassium retained by soil is continually diffusing into the free soil solution and becoming directly accessible to plants.

McCall, Hilderbrandt, and Johnston (28) studied the adsorption of potassium by a sandy loam soil from a solution of potassium chloride containing 62 p.p.m. of potassium. After the first ten minutes in contact with the soil, the solution was reduced to 40 p.p.m. of potassium and to 36 p.p.m. after the second ten-minute period. From this point the adsorption gradually decreased until the solution coming from the soil was almost unchanged. The removal of the adsorbed potassium by distilled water was greatest at first, and then became practically constant. About 42% of the adsorbed potassium was still retained by the soil after six leachings had been made.

Frear and Erb (12) stated that much of the potash applied as fertilizer remained in the surface soil in a state highly available to crops, and that the loss by drainage was probably not great. McGoerge (29), using a sandy textured soil from Honolulu, obtained as high as 45% potassium fixation by leaching with a solution of potassium sulphate containing 214 p.p.m. of potassium.

Starkey and Gordon (42) showed that the hydrogen-ion concentration affected adsorption. Potassium was adsorbed in largest amounts by hydrogel of silica in an alkaline solution, but when the reaction was made acid, the amount of potassium adsorbed was markedly reduced.

Summarizing the work of previous investigators, it is evident that potassium is adsorbed by soils in varying amounts depending upon the existing conditions, kind of soil, and the amount and kind of potassium material applied. From a practical standpoint this adsorption is of considerable importance. In the case of potato growers in Maryland and Virginia, where at the present time applications of from 1000 to 2000 pounds of fertilizer per acre, analyzing from 5% to 8% potash, are made annually, the subject demands unusual attention. Moreover, in the potato-growing sections of these two states, the practice of using larger amounts of potassium in the fertilizer mixtures is probably increasing rather than decreasing. Finally, the loose, friable condition of Norfolk sandy loam, which is used extensively for growing early potatoes and sweet potatoes, adds further interest to the problem.

4. Effect of Salts on Nitrification in Soils.

Phosphorus additions as a rule stimulate bacterial activities but nearly all of the potassium salts very soon become toxic to bacterial action in soil when present in large amounts. The low-grade potassium salts are of especial significance in this respect, probably on account of their high sodium content. Hence, a study of the effects of potassium salts on nitrification is important with respect to the rate and accumulation of nitrates from organic materials added to the soil in a complete fertilizer mixture.

Greaves (16), found that potassium chloride was stimulating to nitrification at low concentrations in the soil but became toxic as the concentration was increased. Potassium sulphate was found toxic at 6 p.p.m. in soil but the toxicity in this case was slow to increase as the salt content was increased. Lipman (24) made perhaps the most extensive study of the effects of alkali salts on the activities of soil bacteria. In his studies, he found that sodium chloride was toxic to the nitrifying organisms at a concantration of 0.1% or less. Sodium chloride was found to be about as toxic for the nitrifying as for the ammonifying organisms. However, a stimulating effect on nitrification was found when sodium chloride was present in very small amounts. In a later publication, Lipman and Sharp (25) found that the nitrogen-fixing organisms were more tolerant to sodium chloride than either the nitrifying or ammonifying organisms. Brown and Hitchcock (6), Gibbs, Batchelor, and Magnuson (15), Patterson and Scott (33), and Lipman (26) all reported a decrease in nitrification in soil when sodium chloride was present in high concentrations.

From the foregoing review of literature it is evident that the amount and kind of fertilizer material, or materials, added to the soil not only affect the nutrition of the growing crop directly, but also indirectly from chemical, physical, and microbiological standpoints. Under these conditions, soil is being constantly adjusted and readjusted to various equilibria. When fertilizers are added to the soil, and crops are grown, it becomes the task of the specialist in soil fertility to determine as far as possible the extent of the chemical, physical and biological changes that have contributed to the final result. This is precisely what has been attempted in the present investigation.

Experimental

Part 1. Fertilizer Studies with Early Potatoes.

General Plan of Experiments. The experimental plots were located 2 miles northeast of Snow Hill, Maryland. In this section of Maryland the predominating soils are the Norfolk, Sassafras, Elkton, and Keyport series. All are characterized by their low nitrogen, phosphoric acid, and potash content.

The topography in the vicinity of Snow Hill may be described as extremely flat with the exception of an occasional sand hill, one of which extended along the western portion of the experimental area, including one entire series of plots.

The soil type used for the experiments was Norfolk sandy loam. This soil is especially low in nitrogen and potassium as may be seen from Table I, which shows the results of a mechanical and partial chemical analysis of a sample of the surface soil taken from the level portion of the experimental area. The subsoil appeared to contain more sand than the surface soil, hence the surface water was normally drained very rapidly.

Weather Conditions: The 4-year average rainfall during the growing seasons of the early potato crops amounted to 11 inches. The rainfall distribution in normal years was good.

Table 1.

Mechanical Analysis*

	Percent.
Fine gravel	1.2
Coarse sand	12.0
Medium sand	12.6
Fine sand	46.4
Very fine sand	8.2
Silt	15.3
Clay	4.4
Water-holding capacity	29.2
Total nitrogen	0.0766
Total potassium	0.8847
pH	6.4
Loss by ignition	2.3

*Mechanical analysis made by Bureau of Chemistry and Soils, U. S. Department of Agriculture.

During the 1927 season the rain gauge at the field registered 2.72 inches for March, 2.88 inches for April, 1.72 inches for May, 2.85 inches for June, and 1.75 inches for July, making a total of 11.9 inches for the growing season. However, during the 1924 growing season, a total of 17.5 inches of rain were recorded, only 5.5 inches for 1925, and 10 inches for 1926.

A thermograph with the bulb placed 6 inches below the surface of the soil was used for recording the soil temperature during the growth of the crop. At the same time, the air temperature was recorded by the same instrument. The average mean soil temperature at a depth of 6 inches was 57.8°F for the 1926 growing season and 65.4°F for the 1927 growing season. The average mean air temperature for the same periods was 64.1°F in 1926 and 59.7°F in 1927.

Description and Management of Plots: The entire experimental area at Snow Hill consisted of approximately 5.2 acres. Of this area 3 acres were used for early potato fertilizer experiments and the remainder was used for fertilizer experiments with sweet potatoes. The plots were 1/40 and 1/20 acre in size and were so arranged in series that the same crop and fertilizer treatments appeared on each plot every two years. This arrangement permitted a study of the accumulative effects of the fertilizer treatments. Early potatoes were rotated with sweet potatoes in every series, with a green manure cover crop on the land during the winter and early spring months.

Fig. 1. One-row fertilizer distributor used for applying all fertilizer treatments.

Where the effect of the green manure cover crop was studied, the land remained bare all winter.

The fertilizer treatments were applied with a one-row distributor illustrated in Fig. I. This method of distribution thoroughly mixed the fertilizer with the surface soil thus minimizing the possibility of fertilizer injury to a large extent. The plots were marked out in six rows 30 inches apart and the fertilizer was applied about March 20th of each year. Planting followed as soon as possible after the fertilizer application. The seed potatoes were treated for scab and cut as nearly as possible in pieces of 1.5 ounces as recommended by Appleman (1). Local grown seed of the Irish Cobbler variety was used throughout the work wherever early potatoes were grown. Planting was done with an Iron Age planter in the usual manner, except for the application of fertilizer which was made as already described. Throughout the growing season, the control of insects was effected in the usual way with Paris green or calcium arsenate. Practically no potato diseases were encountered at any time during the duration of the experiments.

About May 15th of each year, corn was drilled between every other row of potatoes so that three rows of corn were grown per plot in addition to the six rows of potatoes. At

Fig. 2. Showing the size of corn at the time of digging the early potatoes. Photograph taken July 21, 1927.

the time of harvesting the early potato crop, the corn was usually about 18 inches high and did not hinder harvesting operations.

The potatoes were harvested about July 10-15 each year. Digging was done in the manner customary in the locality by using a plow and later scratching out the potatoes by hand. All grading was done in the field using only two grades, U. S. Grade No. 1, Primes, and culls. The weights of primes and culls were recorded in the field at digging time.

For convenience in discussing the results the data have been arranged in a number of series. These series are numbered consecutively and therefore do not necessarily correspond to the actual series numbers given in the field.[1]

Series 1, Influence of Source of Nitrogen in the Fertilizer Mixture.

In this series various nitrogenous materials were compared to study their effect on yield of potatoes when used in a mixture containing 7% ammonia, 6% phosphoric acid, and 5% potash. For all the treatments in this series and throughout

1. The yields for 1924 and 1925 were obtained by Dr. A. M. Smith. Those for 1924 were reported by him in a Doctorate Thesis, University of Maryland, June, 1925.

the work to follow, unless otherwise designated, 16% superphosphate was used as the source of phosphoric acid, and sulphate of potash as the source of potash. The basic fertilizer application for all treatments in this series was 2000 pounds per acre, in accordance with the usual practice where early potatoes are grown in this section. The yields of primes in bushels per acre for each year are shown in Table 2 as well as the average yields of primes, the combined average yields of primes and culls, and the average percent of culls for the four-year period.

An examination of the data presented in Table 2 will show distinctly the beneficial effect on yields of potatoes obtained from the use of organic nitrogenous materials in the fertilizer mixture. In all cases for the entire four years, the yields obtained where the nitrogen was derived from both organic and inorganic sources exceeded those where nitrogen was supplied only in the inorganic form. Where nitrate of soda was the only source of nitrogen, the yields of potatoes were consistently low and the average yield was the lowest obtained from any nitrogen treatment. These results would indicate that nitrate of soda is not a satisfactory nitrogenous material for early potatoes on this soil, when used as the only source of nitrogen in the fertilizer mixture. Smith (41) showed that the losses of nitrate from Norfolk sandy loam by leaching are in proportion to the amount of nitrogen in the fertilizer mixture

Table 2.

Showing the influence of different nitrogenous materials and combinations in a 7-6-5 fertilizer on the yield of Early Potatoes.

Ammonia in Mixture from:	Yield per Acre: Primes 1924	1925	1926	1927	Average: Primes	Primes and Culls	Percent culls Ave.
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	
Nitrate of Soda	68.0	25.0	121.0	118.0	83.0	116.0	28.4
Sulphate of Ammonia	87.5	37.0	154.0	145.0	106.0	133.0	20.3
Dried Ground Fish	127.0	21.0	159.0	167.0	118.5	152.0	22.0
0-6-5 No Ammonia	22.0	19.0	103.0	12.0	39.0	69.0	43.5
Packing House Tankage	155.0	29.0	161.0	131.0	119.0	160.0	25.6
½ Nitrate, ½ Sulphate	114.5	32.0	114.0	149.0	102.4	137.0	25.2
½ Fish, ½ Tankage	147.0	22.0	164.0	134.0	117.0	157.0	25.4
40% Inorganic* 60% Organic**	144.5	26.0	174.0	152.0	124.1	156.0	20.5
50% Inorganic, 50% Organic	146.0	27.0	167.0	162.0	125.5	155.0	19.0
60% Inorganic, 40% Organic.	133.0	20.0	167.0	170.0	122.5	154.0	20.4
0-6-5 No Ammonia	35.0	16.0	96.0	24.0	42.7	73.0	41.5
70% Inorganic 30% Organic	170.0	25.0	155.0	158.0	127.0	157.0	19.1
80% Inorganic, 20% Organic	131.0	32.0	167.0	150.0	120.0	146.0	17.8
Urea	--	39.0	187.0	173.0	133.0	164.0	18.9
Activated Sewage sludge	--	43.0	157.0	203.0	134.3	167.0	19.5

*Inorganic = 1/2 Nitrate of Soda and 1/2 sulphate of ammonia.
**Organic = 1/2 Fish and 1/2 Tankage.

supplied from nitrate of soda. It would seem from this work and the field results presented here that the consistent low yields recorded for nitrate of soda were caused by a direct loss of nitrates from the feeding area of the crop. Sulphate of ammonia, on the other hand gave better yields consistently than nitrate of soda, but when the two materials were mixed, the average yield obtained was slightly lower than where sulphate of ammonia was used alone.

It is evident from the results obtained in Table 2 that the different ratios of inorganic to organic nitrogen used in the mixture did not materially affect the yields of potatoes. From the results, the important consideration in this respect seemed to be the supplying of a part of the nitrogen in the mixture from organic sources with a larger amount supplied from inorganic materials. Of the organic materials used, urea and activated sewage sludge gave the highest average yields, although these yields were calculated from the results of only three years. However, it may be seen from a comparison of the yields from these two materials in 1926 and 1927, that the yields from urea were more uniform than those from sewage sludge. The season of 1925 was unusually dry and a comparison of the yields for that year does not seem warranted.

A further examination of the data given in Table 2 will

Fig. 3. No-fertilizer plot in the foreground and no-ammonia plot on the crest of the sand hill. Photograph taken June 25, 1927.

show conclusively that nitrogen was a limiting factor in potato production on this soil. The average yields of the check plots were less than 50% of those obtained for any treatment, with one exception.

The average percentage of culls obtained for the treatments over the four-year period showed no significant differences when various sources of nitrogen were used. However, there was a tendency toward a lower percentage of culls where organic nitrogen was used in the mixture. The percentage of culls for the check plots was almost double that obtained for the nitrogen-treated plots, with a few exceptions.

Series 2. Comparative effects of different organic and Inorganic Nitrogenous Materials used in the Mixture.

This series of plots was planned principally to compare the relative effects of nitrate of soda, sulphate of ammonia, and Leunasalpeter when used in conjunction with organic materials as sources of nitrogen for potatoes. Several combinations and single sources of nitrogen suggested from the results of Series 1, were also included in this series. The rate of application and the analysis of the fertilizer remained the same as in Series 1, being 2000 pounds of a 7-6-5 mixture. Dried ground fish and packing house tankage in equivalent amounts were used to supply the organic portion of the mixture, except where urea was used. The yields of primes per acre, culls and total yields for 1927 are shown in Table 3.

From Table 3 it may be seen that Leunasalpeter compared very favorably with nitrate of soda and with sulphate of ammonia in combination with fish and tankage. No significant differences in yields were obtained from the various combinations with urea, sulphate of ammonia and nitrate of soda with fish and tankage. Leunasalpeter produced a larger yield of potatoes than urea where each was used as the only source of nitrogen in the mixture. However, the mechanical condition of the mixture containing Leunasalpeter, as the only source of nitrogen, was so bad as to strongly discourage its use in this manner. On the other hand, the mixture containing urea was in excellent mechanical condition at the time it was applied to the soil. The relatively high yield of potatoes obtained in this series where nitrate of soda was used with organics, seems to further strengthen the evidence for the use of organic as well as inorganic nitrogen materials in the mixture.

In an experiment of this kind, results from one year's work do not permit very definite conclusions to be drawn. However, the general conclusion that Leunasalpeter compared very favorably with nitrate of soda and sulphate of ammonia as a source of

Table 3.

Showing the comparative effects of different combinations of nitrogenous fertilizer materials on the yields of early potatoes for 1927.

Ammonia in mixture from:	Yield of Potatoes per Acre. Primes	Culls	Total
	Bus.	Bus.	Bus.
70% Nitrate of soda 30% Organic*	211	27	238
70% Sulphate of Ammonia 30% Organic	192	23	215
70% Leunasalpeter 30% Organic	193	18	211
50% Urea 30% Sulphate of Ammonia 20% Organic	175	19	194
20% Nitrate of Soda 50% Sulphate of Ammonia 30% Organic	175	18	193
Urea	149	23	172
Leunasalpeter	169	23	192

*Organic = 1/2 Fish and 1/2 Tankage.

nitrogen for early potatoes, does seem warranted from the data presented.

Series 3. The effect of a Green Manure Cover Crop in addition to the fertilizer application.

From the foregoing results it is evident that the sources of nitrogen in the fertilizer mixture constituted an important consideration in the fertilizer problem involved in the production of early potatoes on Norfolk sandy loam. However, the potato crop probably was not capable of utilizing all of the fertilizer applied each year. This would mean that the residual effect from the fertilizer would be considerable, unless losses occurred by leaching. It is probable, however, that losses of nitrates, especially, took place rapidly. Hence, the problem of conserving that portion of the fertilizer not utilized by the crop was presented. Intercropping with corn undoubtedly helped to reduce these losses, but an additional reduction was effected by growing a green manure cover crop of rye and vetch on the land during the winter and early spring. Not only should a green manure cover crop conserve the residual fertilizer remaining after the potato crop was removed, but it in turn should considerably increase the amount of organic matter added to the soil each year. In order to study the effectiveness of a green manure cover crop in these respects, a series of seven plots was conducted. These plots received fertilizer treatments identical with seven of the treatments used in Series 1., except that in this case all the plots were allowed to remain bare during the winter and until sweet potatoes were planted the following year. Corn was planted between the rows of early potatoes on these plots as was done on Series 1. For comparison, the yields of prime potatoes for 1925-26-27 are shown in Table 4 together with the average yields for the 3-year period.

From a consideration of the data presented in Table 4 it is apparent that the green manure cover crop did not show a consistent increased yield in 1926. However, the yields for 1925 and 1927 show striking increases in yields for the green manure plots over those obtained for the no-green manure plots. This yearly variation in the results may be explained by the fact that in 1925 and 1927 the plots receiving green manure treatment were located on the sandy hill extending along the west side of the experimental area. In 1926, however, the plots receiving a green manure cover crop were located on a practically level portion of the field where the soil was in a somewhat higher state of fertility. In 1924 the plots were again located on the level portion of the field, but the yields for this year are not given since this was the first year of the experiment and no green manure had been grown the previous winter. It should be further noted that the plots receiving no green

Table 4.

Showing the effect of a green manure cover crop in addition to fertilizer treatment on yields of Early Potatoes.

Ammonia in mixture from:	Yield Primes per Acre. 1925	1926	1927	3-year Average
	Bus.	Bus.	Bus.	Bus.
Nitrate of Soda	25.0	121.0	118.0	88
Nitrate of Soda plus Green Manure	52.0	116.0	193.0	120
Sulphate of Ammonia	37.0	154.0	145.0	112
Sulphate of Ammonia plus Green Manure	63.0	140.0	175.0	126
Dried Ground Fish	21.0	159.0	167.0	116
Dried Ground Fish plus Green Manure	64.0	176.0	191.0	144
40% Inorganic, 60% Organic*	26.0	174.0	152.0	117
40% Inorganic, 60% Organic plus Green Manure	59.0	165.0	204.0	143
50% Inorganic, 50% Organic	27.0	167.0	162.0	116
50% Inorganic, 50% Organic plus Green Manure	64.0	152.0	199.0	138
60% Inorganic, 40% Organic	20.0	167.0	170.0	119
60% Inorganic, 40% Organic plus Green Manure	71.0	131.0	226.0	143
70% Inorganic, 30% Organic	25.0	155.0	158.0	113
70% Inorganic, 30% Organic plus Green Manure	62.0	146.0	225.0	144

*Organic = 1/2 Fish and 1/2 Tankage
Inorganic = 1/2 Sulphate of Ammonia and 1/2 Nitrate of Soda.

manure were located on level land during the entire four years of the experiment. The yields for the green manure and no-green manure plots are in one sense, not comparable in 1925 and 1927, as a comparison for these years accentuates the returns for green manure. On the other hand, a comparison of the yields for these years is interesting since it brings out the relative increases that may be expected from green manures when used in conjunction with fertilizer applications on the sand hills that occur in this section.

The occurrence of decreases in yields of potatoes where a green manure crop was used in 1926 is rather hard to explain. However, these decreases may have been caused by a retardation of bacterial action in the soil brought about by the plowing under of the green manure in the Spring. This in turn may have retarded the nitrification of the organic materials added in the fertilizer. The extent of this action would, of course, depend upon the quantity of green manure plowed under and the nitrogen-carbon ratio of both the soil and the green manure.

In consideration of the results obtained for 1925 and 1927, especially for the latter year, since 1925 was an unusually dry year, it is especially noteworthy that the yields of potatoes were increased in every case where a green manure crop was used, even though these plots were located on the sandy hill. The results from the use of a green manure crop under these soil conditions were undoubtedly very largely brought about by the fertilizer residues remaining in the soil after the sweet potatoes had been dug the previous year. Without this residual fertilizer, it is very probable that the results would not have been so satisfactory, since the green manure crop in this case would undoubtedly have made a very poor growth.

Series 4. Rates of fertilizer applications and the value of organic nitrogen applied at planting time in relation to yields of early potatoes.

The fertilizer used in this series contained 7% ammonia, 6% phosphoric acid, and 5% potash applied at the different rates shown in Table 5. The nitrogen in the mixture was derived from equivalent amounts of nitrate of soda, sulphate of ammonia, dried ground fish, and packing house tankage. Phosphoric acid and potash were supplied from the same sources as in the previous series. The usual procedure was followed throughout in applying the fertilizer, applying 75% at the time of planting the potatoes and the remaining 25% at the first cultivation of the crop. However, for one treatment at each rate of application, except for the highest rate, only organic nitrogenous materials were contained in the portion of the mixture applied at planting-time. In these cases, the remainder of the mixture, containing only nitrogen derived from nitrate of soda and sulphate of ammonia, was applied at the first cultivation. At each rate of application the total amount and analysis of fertilizer was the same, the only difference being the time at which the inorganic nitrogen was applied. The yields of early potatoes produced in 1927 on these plots expressed in bushels per acre together with the average yields obtained in 1926 and 1927 from the rate-of-application plots are given in Table 5. The study made on the effect of deferred inorganic nitrogen application was begun in 1927, consequently only one year's results are given for this work.

The data presented in Table 5 show that there was a decrease in yields of potatoes in every case where the application of soluble inorganic nitrogen was deferred until the potatoes were cultivated. The yields were consistently lower for these plots even at the higher rates of application. During the growing season there was very little difference noticeable in the appearance of the potato vines on the plots differently treated with respect to the nitrogen application. However, it seems apparent from the yields obtained, that the utilization of available nitrogen at the earliest growth of the potato plant is an important consideration in fertilizing this crop. It should be borne in mind that the results obtained are for one year only and therefore do not warrant definite conclusions being drawn, yet the consistency of the results is very significant.

In considering the average yields of the potatoes produced on the rate-of-application plots for 1926 and 1927, it

Table 5.

Showing the Effect of Deferring the Inorganic Nitrogen Application and Also the Effect of Rate of Application on Yields of Early Potatoes.

Pounds 7-6-5 Fertilizer per Acre.	Yield of Primes per Acre.	
	1927	Average 1926-27
	Bus.	Bus.
No fertilizer	17	17.5
1000 pounds	151	127.0
1000 pounds*	123	
1500 pounds	219	187.0
1500 pounds*	152	
2000 pounds	217	180.0
2000 pounds*	205	
No fertilizer	51	35.5
2500 pounds	268	222.5
2500 pounds*	211	
3000 pounds	253	215.5

*Indicates deferred inorganic nitrogen application.

would seem that the 1500-pound application was the most profitable rate. However, the actual value of the applications cannot be determined unless the cost of the fertilizer used and the prices received for potatoes are given consideration. This phase of the problem offers a very interesting economic study for further work.

Series 5. A Comparison of Verying Amounts of Different Potassium Materials Used in the Fertilizer Mixture for Early Potatoes.

An extensive series of plots 1/40 acre in size was laid out in 1927 for the purpose of studying the relative effects of muriate of potash, sulphate of potash, and manure salts (20%) on the yields of early potatoes. The three materials were used to supply equivalent quantities of potash amounting to 5, 8, and 10% in mixtures containing in each case, 7% ammonia and 6% phosphoric acid. Seventy percent of the ammonia in the mixture was derived from equivalent amounts of nitrate of soda and sulphate of ammonia, and 30% from equivalent amounts of dried ground fish and packing house tankage. The phosphoric acid was supplied by 16% superphosphate as usual.

To eliminate soil variations, the treatments were replicated two times and the replicate plots were distributed systematically over the field. The entire arrangement of the plots was repeated in an adjoining field for a similar study with sweet potatoes. By this arrangement, a rotation of early potatoes with sweet potatoes was made possible without varying the potash treatment on any one plot for either crop. Moreover, a study of the residual effects of the treatments was also made possible. The experiment was conducted in the same manner as the previous series, using corn as an intercrop with rye and vetch for a green manure cover crop during the winter. The average yields of potatoes produced on the triplicate plots for 1927 are given in Table 6 together with the average yields for four check plots.

The results obtained from the different treatments for 1927 are not conclusive as to the value of the different potash materials for early potatoes. At best, the first year of an experiment of this kind with potash materials can only be expected to give an indication of the results that may be obtained after a longer period. Accordingly, the results will be discussed on this basis.

One of the outstanding points of the experiment was the larger average yields of potatoes obtained where potash was used as compared to the yields obtained where no potash was used. Evidently, potash as well as nitrogen is needed to obtain maximum yields of potatoes on this soil. The yields obtained from the check plots over a period of years should be very interesting from a plant nutrition standpoint. Although the check plots gave an average yield of 124 bushels for 1927, yet the plants on

Table 6.

Showing the Yields of Early Potatoes when Various Potassium Materials were used in Different Amounts in the Fertilizer Mixture.

Potash in Mixture from:	Average yields per acre of triplicate plots								
	7-6-5			7-6-8			7-6-10		
	Primes Bus.	Culls Bus.	Total Bus.	Primes Bus.	Culls Bus.	Total Bus.	Primes Bus.	Culls Bus.	Total Bus.
Manure salts(20%)	199	23	222	200	22	222	224	14	238
Muriate of Potash	225	21	246	209	28	237	226	20	246
Sulphate of Potash	211	20	231	196	25	221	209	28	237
No Potash 7-6-0*	124	29	153						

*Average yields of four check plots.

Fig. 4. No-potash plot receiving 7-6-0 fertilizer at the rate of 2000 lbs per acre. Note potash hunger symptoms. Photograph taken June 25, 1927.

these plots exhibited typical potash hunger symptoms, especially during early growth. The leaves were small, curled, and of a dark green color that almost shaded into purple in some instances. Such leaf coloration has been known to be associated with potash-hunger as early as 1867. In this year Voelcker (48) noted the dark green color of the leaves of mangolds grown on land where no potash salts were applied. The color of the leaves of the potato plants growing on the plots variously treated with respect to potash in the present experiment, corresponded very closely to the color variations observed by Voelcker with mangolds. The lightest leaf coloration was observed on the plots receiving manure salts. The cause of this gradation of leaf color with different potash treatments offers a very interesting study in plant nutrition.

A point of interest brought out from an examination of the data given in Table 6 is the lower average total yields obtained where manure salts were used in the mixture in comparison to the yields obtained with muriate or sulphate of potash. This effect of manure salts may have been a direct osmotic effect on the young potato plants or an indirect effect. The sodium chloride applied with the manure salts may have retarded the nitrification of the organic materials applied in the fertilizer, and thus affected the yields indirectly. This subject will be treated at length in the work to follow.

From a further examination of Table 6 it would seem that the potash materials may be arranged in the following order in relation to the increases in yields obtained over the check plots: first, muriate of potash; second, sulphate of potash; third, manure salts. It also may be noted from Table 6 that no significant increases in yields of prime potatoes were obtained for any of the potash materials when applied in amounts above the equivalent to 5% potash. These results are in accord with those obtained by Johnston (19) and others.

Total starch determinations using the Official acid-hydrolysis method (2) were made on several samples of the potatoes from different plots. The samples taken from the check plots receiving no potash showed the same starch content as the samples of potatoes taken from the plot receiving a 7-6-10 fertilizer with the potash from sulphate.

Series 6. Effect of a Double Strength Fertilizer applied at Half the Usual Rate.

Two fertilizer mixtures were made up for this experiment, one containing 14% ammonia, 12% phosphoric acid, and 10% potash and the other containing the same amounts of ammonia and potash but only half the amount of phosphoric acid. The rate of application was 1000 pounds per acre. The ammonia in the mixtures was derived entirely from urea, the phosphoric acid from 20% superphosphate, and the potash from sulphate of potash. The yields of potatoes produced in 1927 on 1/40 acre plots where these treatments were applied are given in Table 7 in bushels per acre.

The location of these plots was adjoining those of Series 2., therefore, a comparison of the yields given in Table 7 with those in Table 3 can be made. Such a comparison shows that the 14-12-10 mixture, applied at the rate of 1000 pounds per acre, compared very favorably with the 7-6-5 mixtures applied at double that rate. However, the 14-6-10 mixture at 1000 pounds per acre produced a slightly lower yield of potatoes than was obtained with the 14-12-10 mixture. It would seem from the results for 1927 with concentrated mixtures, that no damage was caused to the crop by their use. If the rate of application of concentrated mixtures is made commensurate with the increase in analysis, as compared with the 7-6-5 mixtures, there will probably be little danger from fertilizer injury.

Part 2. Fertilizer Studies with Sweet Potatoes.

Nearly three acres of the entire experimental area were used for experiments with fertilizers on sweet potatoes, the remaining three acres being used for the experiments with early potatoes. The soil, mapped as Norfolk sandy loam, is characteristically low in nitrogen, phosphorus, and potash. Because of its sandy nature, it is also subjected to con-

Table 7.

Showing Yields of Early Potatoes Obtained with Concentrated Mixtures.

Analysis	Rate per Acre	Yield potatoes per Acre		
		Primes	Culls	Total
		Bus.	Bus.	Bus.
14-12-10	1000 lbs.	208	24	232
14- 6-10	1000 lbs.	192	28	220

siderable leaching during the wet months of summer and winter. The amount of rainfall for the sweet potato growing season of each year, as taken from the records made at Public Landing, Maryland, seven miles from the Experimental Field, was as follows: 1925, 11.18 inches; 1926, 24.42 inches; 1927, 19.41 inches.

Plots of 1/20 and 1/40 acre in size were used, and these were so arranged as to allow for the continued application of the same fertilizer materials on each plot year after year. Only the rate and analysis of fertilizer varied each year. Such an arrangement was made in order to study the residual effects of the fertilizers applied. Rye and vetch were seeded after the potatoes were dug and served as a green manure cover crop on the land until the following spring. In one series the land was left bare, in order to make a comparative study of green manuring on yields as was done in the case of early potato investigations.

The fertilizer treatments were applied in the row with a one-row fertilizer distributor about May 20-23 of each year, and the sweet potato sprouts were transplanted as soon after this as possible. Locally grown sprouts of the Big Stem Jersey variety of sweet potato were planted, using a transplanting machine whenever possible. It should be noted particularly that the entire amount of fertilizer in all of the treatments was applied before the sprouts were transplanted.

Harvesting operations were usually commenced about October 10th, depending upon the season and the market conditions. The potatoes were plowed up and later scratched out by hand in the manner customary in the locality. All grading was done in the field using three grades, U. S. Grade No. 1, primes, culls, and strings. The weights of primes and culls were recorded in the field at harvest, the strings being discarded.

Throughout the entire work it should be noted particularly that no single treatments of fertilizer materials were made for comparison. Treatments of this sort were not made, on account of the fact that previous work and local cultural practices indicated that a complete fertilizer was more suitable for the production of satisfactory yields of sweet potatoes. In discussing the present work the results of the different experiments have been arranged in series and numbered in consecutive order for convenience. The series numbers, therefore, do not correspond in all cases with those used in the field.

Series 1. Influence of different forms of nitrogen in the fertilizer mixture for sweet potatoes.

The purpose of this series was to make a comparative study of certain inorganic and organic nitrogenous materials, when used alone and in combinations in the fertilizer mixture. The fertilizer used for each treatment, except for the check plots, was made up to contain the equivalent of 3% ammonia, 8% phosphoric acid, and 8% potash. The phosphoric acid and potash for this series and all subsequent work, unless otherwise stated, were derived from 16% superphosphate and sulphate of potash, respectively. The application was made at the rate of 1000 pounds of fertilizer per acre, in the same manner as previously described. The yields of prime potatoes for 1925, 1926, and 1927, the average yield for the three-year period, and the average yield in bushels per acre, are given in Table 8. together with the average percentage of culls for each treatment.

In consideration of the yields of potatoes which were obtained from the different treatments for each year, it is quite evident that the results varied considerably from year to year. In 1925, undoubtedly, the extreme droughth caused a general depression of all the yields, so that moisture and not fertilizer appeared to be the limiting factor during this year. Therefore, the present discussion will be confined to the results obtained during the following two years, 1926 and 1927.

The most important results for 1926 and 1927 were obtained where nitrate of soda, sulphate of ammonia, and urea were used alone as sources of nitrogen in the fertilizer mixture. The yields from these plots, when compared with those obtained from

Table 8.

Showing the Yield of Sweet Potatoes from Plots Treated with Varying Amounts of Different forms of Nitrogen in a 3-8-8 Fertilizer.

Ammonia in mixture from:	Yield Primes per Acre.				Total yield Ave.	Percent Culls Ave.
	1925	1926	1927	3-yr. Ave.		
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.
Nitrate of Soda	12	245	152	136	184	26.0
Sulphate of Ammonia	11	184	147	114	142	19.7
Dried Ground Fish	8	170	86	88	142	38.0
0-8-8, No ammonia	9	39	76	41	91	54.9
Packing House Tankage	14	118	81	71	136	47.7
½ Sulphate and ½ Nitrate	11	168	74	84	138	39.1
½ Fish and ½ Tankage	16	106	116	80	140	42.8
40 Inorganic* 60% Organic**	11	155	143	103	166	37.9
50% Inorganic, 50% Organic	25	95	132	84	163	48.4
60% Inorganic, 40% Organic	18	192	107	106	161	34.1
0-8-8 No Ammonia	46	40	136	74	124	40.3
70% Inorganic, 30% Organic	53	201	43	99	151	34.4
80% Inorganic, 20% Organic	78	120	73	90	157	42.6
Urea	5	143	204	117	165	29.0
Activated Sewage Sludge	20	123	148	97	155	37.4

*Inorganic = 1/2 Nitrate of Soda and 1/2 Sulphate of Ammonia

**Organic = 1/2 Fish and 1/2 Tankage.

the plots receiving nitrogen only in the organic form, serve to show the importance of soluble mineral nitrogenous compounds in the fertilizer mixture for sweet potatoes. An average yield of 136 bushels of potatoes was produced where nitrate of soda was used as a single source of nitrogen, and an average yield of 114 bushels was produced where sulphate of ammonia was similarly used. However, only an average yield of 88 bushels of potatoes was produced with dried ground fish as the only source of nitrogen. A still lower average yield of 71 bushels was obtained where packing house tankage was used. From these results it would seem, that sweet potatoes required a soluble nitrogen material to produce the best yields on this soil. It is possible that the nitrification of the organic materials, did not take place rapidly enough to supply a sufficient amount of nitrates, during the critical period of growth soon after the sweet potato sprouts were transplanted. Moreover, it is wholly possible that a supply of nitrates was prolonged throughout the first part of the growing season, in the cases where organic materials were used. The deferred supply of nitrates may have induced late vine growth and thus retarded the processes of carbohydrate storage in the roots. This phase of the problem offers a very fruitful field of research which perhaps may be found closely associated with the work of Kraus (23), and others, on the carbon-nitrogen relations in plants, as modified by the supply of nutrients in the soil. Some greenhouse studies with sweet potatoes have already been commenced for the purpose of studying this phase of the problem, but the work has not progressed far enough to give results.

A comparison of the average yields produced where only soluble nitrogen materials were used, shows the highest average yield where nitrate of soda was applied. However, from the standpoint of smoothness and quality, the potatoes produced where urea was used in the mixture, were far superior to those produced on any other plot in the series. With respect to the relative mechanical conditions of the mixtures, it is worthy of note that the urea mixture could be drilled without the slightest diffuclty, whereas the nitrate of soda and sulphate of ammonia mixtures, had to be remilled before they could be drilled.

Of the various treatments containing different percentages or inorganic and organic nitrogen, none seemed to be especially superior. However, the 60% inorganic and 40% organic ratio gave the highest 3-year average yield of all the combinations. It is evident from Table 8 that mineral nitrogenous materials, used alone in the fertilizer mixture, outyielded the treatments containing both inorganic and organic materials. However, conclusions should not be drawn from these results without a consideration of the soil conditions that usually exist where the sweet potato crop is grown. It is a well known fact that sweet potatoes grow best on loose sandy soils. Naturally, losses of nitrates from such a soil during wet seasons are heavy. For this reason, and also to provide for a better mechanical condition of the mixture, it would seem safer to supply the nitrogen from both organic and inorganic sources. The 60% inorganic and 40% organic ratio appears to be a good combination for this soil.

The percent of culls produced was perhaps influenced greater by seasonal differences than any other contributing factor. However, from Table 8, it may be noted that three plots produced lower average percentages of culls than any of the others. It is significant that the treatments for these plots were, nitrate of soda, sulphate of ammonia, and urea, all used alone as sources of nitrogen in the fertilizer mixture.

Series 2. Comparative Effects of Certain of the Newer Nitrogen Compounds used in a Fertilizer mixture for Sweet Potatoes.

This series of plots was laid out in 1927 for the purpose of studying the effects on yield of sweet potatoes, when nitrate of soda, sulphate of ammonia, Leunasalpeter, and urea, were used in the fertilizer mixture in various ways. Wherever organic nitrogen was used in this series, it was supplied in equivalent amounts from dried ground fish and packing house tankage. The fertilizer analysis was the same as that used for Series 1, being a 3-8-8 mixture. The treatment, however, was applied at the rate of 1500 pounds per acre instead of 1000 pounds as was done previously. The entire amount of each fertilizer treatment was applied as usual before the sprouts were transplanted. The yields of primes, culls, and total yield for the different treatments in 1927, are shown in Table 9.

The results given in Table 9 indicate that, under the conditions of the experiment, Leunasalpeter plus organics, was a combination as suitable for sweet potatoes, as was nitrate of soda or sulphate of ammonia also used with organics. The yield of primes produced on the plot treated with Leunasalpeter plus organics, was somewhat higher than that obtained from nitrate of soda, but it was about the same as that produced with sulphate of ammonia. However, when used alone in the mixture, Leunasalpeter produced a yield of primes, 20 bushels lower than that which was obtained with urea. Here again, however, the total yields were about the same.

From the results of the various combinations, it would seem that both urea and Leunasalpeter produced better yields when they were used with organic nitrogenous materials. It is possible that another year's results will show more conclusively how these materials may best be used for sweet potatoes, but it will be necessary to have several year's data, before the effect of variations in seasons can be considered.

Table 9.

Showing the Effects on Yield of Sweet Potatoes when Different Nitrogenous Materials were used in a 3-8-8 Fertilizer in 1927.

Ammonia in mixture from:	Yield potatoes per acre. Primes Bus.	Culls Bus.	Total Bus.
70% Nitrate of Soda, 30% Organic*	130	15	145
70% Sulphate of Ammonia, 30% Organic	146	61	207
70% Leunasalpeter, 30% Organic	159	56	215
50% Urea, 30% Sulphate of Ammonia, 20% Organic	182	55	237
20% Nitrate of Soda, 50% Sulphate of Ammonia, 30% Organic.	171	48	219
Urea	146	33	179
Leunasalpeter	126	51	177

*Organic = 1/2 Fish and 1/2 Tankage.

Series 3. The Effect of a Green Manure Cover Crop in Addition to a Fertilizer Application for Sweet Potatoes.

The question of conserving the portion of the fertilizer not utilized by the sweet potato crop, is as important in growing this crop, as it is in every case where large amounts of fertilizer are applied to crops grown on sandy soils. To effect this conservation, in these experiments, the land was disced thoroughly after the sweet potatoes were harvested and rye and vetch seeded. For determining the relative effect of green manuring, seven treatments, duplicating certain treatments in Table 8, and applied in the same manner, were used in Series 3 but without a green manure cover crop. By this arrangement, a comparison of different fertilizer treatments with and without green manure was made possible. The yields of primes for each treatment for 1925, 1926, and 1927, together with the average yield over the three-year period, are shown in Table 10.

In considering the data presented in Table 10, it becomes necessary to disregard the yields for 1925, as the dry weather during that season evidently seriously affected the entire sweet potato crop. In 1926, the plots receiving green manure were located on a sandy hill, whereas the no-green manure plots were situated on comparatively level land. As a consequence, the increases shown for green manure in 1926, are very likely due in part, to soil differences. Furthermore, it may be seen from

Table 10.

Showing Effect of Green Manure Cover Crop in Addition to Fertilizer Treatment on the Yield of Sweet Potatoes.

Ammonia in mixture from:	Yield primes per acre			
	1925	1926	1927	3-year Average
	Bus.	Bus.	Bus.	Bus.
Nitrate of Soda	37	173	56	89.0
Nitrate of Soda plus green manure	12	245	152	136.0
Sulphate of Ammonia	46	157	31	78.0
Sulphate of Ammonia plus Green Manure	11	184	147	114.0
Dried Ground Fish	29	148	13	63.0
Dried Ground Fish plus Green Manure	8	170	186	88.0
40% Inorganic*, 60% Organic**	30	136	48	71.0
40% Inorganic, 60% Organic plus Green Manure	11	155	143	103.0
50% Inorganic, 50% Organic	30	180	40	83.0
50% Inorganic, 50% Organic plus Green Manure	25	95	132	84.0
60% Inorganic, 40% Organic	37	156	42	78.0
60% Inorganic, 40% Organic plus Green Manure	18	192	107	106.0
70% Inorganic, 30% Organic	33	139	57	76.0
70% Inorganic, 30% Organic plus Green Manure	53	201	43	99.0

*Inorganic = 1/2 Nitrate of Soda and 1/2 Sulphate of Ammonia
**Organic = 1/2 Fish and 1/2 Tankage.

Table 10 that better yields were produced on the sandy hill in 1926, than were obtained in 1927 on the level land. However, in 1927 all plots were located on the level portion of the field, and it may be seen from the data, that increases for green manure still persisted.

In considering the three-year average yields, it will be noted from Table 10. that the relative increases for green manure were greater where nitrate of soda and sulphate of ammonia were used, than where dried ground fish was used. Evidently, the maximum returns were obtained from the soluble nitrogen materials, only in conjunction with a sufficient supply of organic matter in the soil, as in the case where green manures were applied each year. Dried ground fish appeared to be an unsuitable material when used alone in the mixture, even when green manures were supplied in addition to the fertilizer treatment. For the inorganic-organic combinations, the greatest increases for green manure were obtained with the 40-60 and the 60-40 ratios. The yields obtained for the 50% inorganic and 50% organic nitrogen ratio were about the same where green manure was added, as where the land was left bare.

From a comparison of the yields obtained with and without green manure in addition to the fertilizer treatment, it would seem that the use of green manures as a whole produced consistent increases in yields of potatoes.

Series 4. The Effect of Different Rates of Fertilizer Applications on Yield of Sweet Potatoes.

A fertilizer mixture containing 3% ammonia, 8% phosphoric acid, and 8% potash was used for all treatments in this series. The ammonia was supplied by equivalent amounts of nitrate of soda, sulphate of ammonia, dried ground fish, and packing house tankage. The phosphoric acid and potash were derived from 16% superphosphate and sulphate of potash, respectively. The fertilizer treatments were applied in the row just before transplanting the sweet potato sprouts. The yields of primes and total yield for 1926 and 1927 are shown in Table 11, together with the average yields for the two-year period.

It is evident from the data presented in Table 11, that from the standpoint of yields of potatoes, the best rate of fertilizer application was between 1000 and 1250 pounds per acre. The gradual increase in yields as the fertilizer application was increased from 500 to 1000 pounds per acre, is strikingly significant. Likewise, the reduction in yield when the application was increased from 1250 to 1500 pounds per acre, is equally significant. Considering the average increases in yields for the 500 and 750 pound applications over the yields from the check plots, it seems very likely that fertilizer applications at these rates would prove unprofitable on this soil. The decreased yield for the 1500-pound application undoubtedly was caused by an injurious effect of a high concentration of fertilizer salts.

Table 11.

Showing the Yields of Sweet Potatoes Produced with a 3-8-8 Fertilizer Applied at Different Rates.

Pounds 3-8-8 Fertilizer per Acre.	Yield potatoes per acre.					
	1926		1927		Ave. 1926-27	
	Primes	Total	Primes	Total	Primes	Total
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.
No fertilizer	19	121	55	88	37	105
500 pounds*	86	107	101	145	94	126
750 pounds*	119	178	152	201	136	190
1000 pounds*	120	166	204	244	162	205
No fertilizer	65	133	130	177	98	155
1250 pounds	146	202	203	231	175	217
1500 pounds	107	163	168	219	138	191

*Indicates average yields of duplicate plots.

Series 5. A Comparison of Varying Amounts of Different Potassium Materials used in the Fertilizer Mixture for Sweet Potatoes.

In the spring of 1927, a series consisting of thirty-one 1/40-acre plots was laid out in order to study the relative effects of muriate of potash, sulphate of potash, and manure salts (20%), in a complete fertilizer mixture for sweet potatoes. Each potash material was used to supply equivalent quantities of potash amounting to 5, 8, and 10%, in a mixture containing 3% ammonia and 8% phosphoric acid. Seventy percent of the ammonia was derived from equivalent amounts of nitrate of soda and sulphate of ammonia and 30% from equivalent amounts of dried ground fish and packing house tankage. The phosphoric acid was supplied by 16% superphosphate.

The treatments were applied in triplicate, so that soil variations could be minimized. As a further precaution, in this respect, the triplicate plots were so located in the series as to utilize part of a representative soil area in three portions of the field. Although the field on which the experiment was located was very uniform in all respects, it was thought advisable to provide several replicate plots for each treatment for the purpose of obtaining material for certain physiological studies, that will be carried on from time to time during the progress of the work. Four check plots were provided, each receiving a 3-8-0 fertilizer application.

The plots were managed in the same manner as in the preceeding series, except that the fertilizer was applied at the rate of 1500 pounds in each case. A green manure cover crop of rye and vetch was seeded, as usual, when the sweet potatoes had been dug. In Table 12 are shown the average yields of primes, culls, and the total yield for the triplicate treatments in bushels per acre, together with the average yield of the four check plots for 1927.

The data presented in Table 12 show rather definitely, at least for one year's results, that additions of potash to this soil increased the average yield of sweet potatoes. However, a careful examination of Table 12 does not show a uniform response from all the potash materials used. Equivalent amounts of potash supplied by manure salts, in every case, produced a lower average yield of prime potatoes than either muriate or sulphate of potash. Furthermore, it is significant that there were no uniform increases in average yields for the 10% potash applications, over the 5 and 8% potash treatments. Sulphate of potash produced the largest average yield of prime potatoes where the 8% potash mixture was used, but muriate of potash produced the largest yield from the 5% potash mixture. In the case of manure salts, it is probable that the total salt content was high enough to retard the early growth of the young sweet potato sprouts to some extent. On the other hand, it is entirely probable that the large quantity of sodium chloride which was applied with the manure salts may have retarded the nitrification

Table 12.

Showing the Yield of Sweet Potatoes Obtained with Various Potash Materials used in Different Amounts in the Fertilizer Mixture in 1927.

Potash in mixture from:	Average yields per acre of triplicate plots								
	3-8-5			3-8-8			3-8-10		
	Primes	Culls	Total	Primes	Culls	Total	Primes	Culls	Total
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.
Manure salts(20%)	129	67	196	103	53	156	126	52	178
Muriate of Potash	167	45	212	109	44	153	134	68	202
Sulphate of Potash	157	48	205	174	59	233	151	63	214
No Potash 3-8-0*	99	65	164						

*Average yields of four check plots.

of the organic materials contained in the fertilizer mixture. This toxic action, although probably not capable of stopping nitrification entirely, may have prolonged the supply of nitrates into the growing season, so that there was a tendency for vine growth to occur at a time when the plant would normally be producing carbohydrates for root storage. The toxic effect of large amounts of sodium chloride on nitrification is well known and will be discussed later in connection with the use of manure salts in fertilizers for potatoes.

From the first year's results for the comparative effects of various potash materials with sweet potatoes, it appears that sulphate of potash was slightly superior to muriate of potash. Whether the increased yields produced from the use of sulphate of potash will justify the additional cost of this material, is a matter that will probably be brought out as the experiment continues. In the case of manure salts, it appeared that this material, when compared on an equivalent basis with muriate or sulphate of potash, was not as suitable as either of these materials when used for sweet potatoes on this soil.

Series 6. Effect of Double Strength Fertilizers Applied at Half Rate for Sweet Potatoes.

Experience has shown that the period shortly after the sweet potato sprout is transplanted is a critical stage in its development. At this time, it is possible to seriously retard the growth of the plant by improper application of fertilizers, so that the stand will be scattered and a poor yield of potatoes result. With the introduction of highly concentrated fertilizers, the question arose as to their effect when used for sweet potato production. In order to obtain some experimental information in this regard, two treatments of high analysis fertilizers were each applied to 1/40 acre plots. These plots were situated close to those in Series 2 so that comparisons could be made with the usual fertilizer treatments. One of the fertilizer mixtures was made up to contain 6% ammonia, 16% phosphoric acid, and 16% potash, being a double 3-8-8 mixture. The other mixture contained the same amounts of ammonia and potash but only half the amount of phosphoric acid. All the ammonia in the mixtures was derived from urea, the phosphoric acid from 20% superphosphate, and the potash from sulphate of potash. Both mixtures were applied at the rate of 750 pounds per acre before the sprouts were transplanted. The yields of primes, culls, and the total yields expressed in bushels per acre for each treatment, are given in Table 13.

It appears from the yields given in Table 13 that no harmful effect was produced when the concentrated mixtures were applied at the rate of 750 pounds per acre. These yields compared very favorably with those produced where a 3-8-8 mixture, made from similar materials, was applied at 1500 pounds per acre. It will be noted from Table 13 that the yield of potatoes was not appreciably reduced when the usual quantity of phosphoric acid

Table 13.

Showing Yield of Sweet Potatoes Produced where

Concentrated Mixtures were used in 1927.

Analysis	Rate per Acre	Yield potatoes per Acre		
		Primes	Culls	Total
		Bus.	Bus.	Bus.
6-16-16	750 pounds	163	70	233
6- 8-16	750 pounds	147	67	214
3- 8- 8	1500 pounds	146	33	179

was reduced to half that amount. This result, and those obtained in the foregoing studies, indicate that phosphoric acid is not as essential in the production of sweet potatoes as nitrogen and potassium.

Although no harmful effects were noticeable where concentrated mixtures were used in 1927, it is possible that different results may be obtained during a season of lower rainfall. For this reason, it seems advisable to have the results for several seasons before more definite conclusions can be drawn with respect to the use of concentrated mixtures.

Part 3. Adsorption and Nitrification Studies with Norfolk Sandy Loam.

Preliminary Experiment.

A series of 10 leaching cylinders similar to those described by Smith (41) were set up and each was filled with 5500 grams of Norfolk sandy loam soil. This soil was obtained from the surface soil of the experimental fields at Snow Hill, Maryland, and was mixed thoroughly and screened to remove remains of plants and other coarse material. The mechanical analysis of the soil as determined by the U. S. Bureau of Chemistry and Soils is given in Table 1.

Applications of 5.5 grams of fertilizers analyzing 7-6-5, 7-6-8, and 7-6-10 were mixed with the upper three inches of soil in each cylinder. This application corresponds to a broadcast application of 2000 pounds per acre. Potassium sulphate, potassium chloride, and manure salts were used alone to supply equivalent amounts of potash at all three rates, so that three sources of potassium could be compared for each rate of application. The phosphoric acid was supplied by 16% superphosphate and the nitrogen was supplied by nitrate of soda, sulphate of ammonia, packing house tankage, and dried ground fish in equivalent amounts from all four sources. One cylinder was treated with a 7-6-0 mixture for a check. The cylinders were leached every two weeks for 16 weeks with 860 c.c. of distilled water, and the leachings were collected for analysis. This rate of leaching approximated the average rainfall during the growing season of the early potato crop at Snow Hill, Maryland, which amounted to 11 inches.

Potassium determinations were made gravimetrically following the method described by Stewart (43), using a 300 c.c. aliquot. At the start, it was planned to determine the amount of potassium in each series of leachings in order to calculate the loss of potassium from the soil, but the results of the determinations on the first three series of leachings made a change in the work necessary. Only traces of potassium could be detected in the leachings for the first three series after 2580 c.c. of distilled water had been added. Consequently, it was decided to restrict the study to the translocation of potassium in the soil.

The leachings were continued at the regular intervals, and after the last leaching had been made, the soil in each cylinder was sampled by taking a boring of the entire depth of the soil column with a brass tube. The soil column thus obtained was divided into three equal portions. The middle portion was discarded and total potassium determinations were made on the upper and lower portions using the official method (2). The results of these determinations showed no significant differences in the potassium content of the soil at the different depths, regardless of the amount and source of potassium used.

From this preliminary work it would seem that, regardless of the sandy texture of this soil, there was an appreciable adsorption of the potassium applied. An experiment was then planned to determine the relative rate of potassium adsorbed from strong solutions of potassium salts, in order to arrive at the adsorption capacity of the soil.

Description of Apparatus

To carry out the leaching work, the simple apparatus shown in Fig. 5 was set up. Before adding the soil to the extraction funnel, a few pieces of HCl-washed gravel were placed in the bottom so that the soil would not clog the outlet during leaching. The outlet tube in the reservoir was provided to maintain atmospheric pressure above the liquid in order to permit a constant flow of solution from the bottle. By carefully regulating the flow of solution in and out of the extraction funnel,

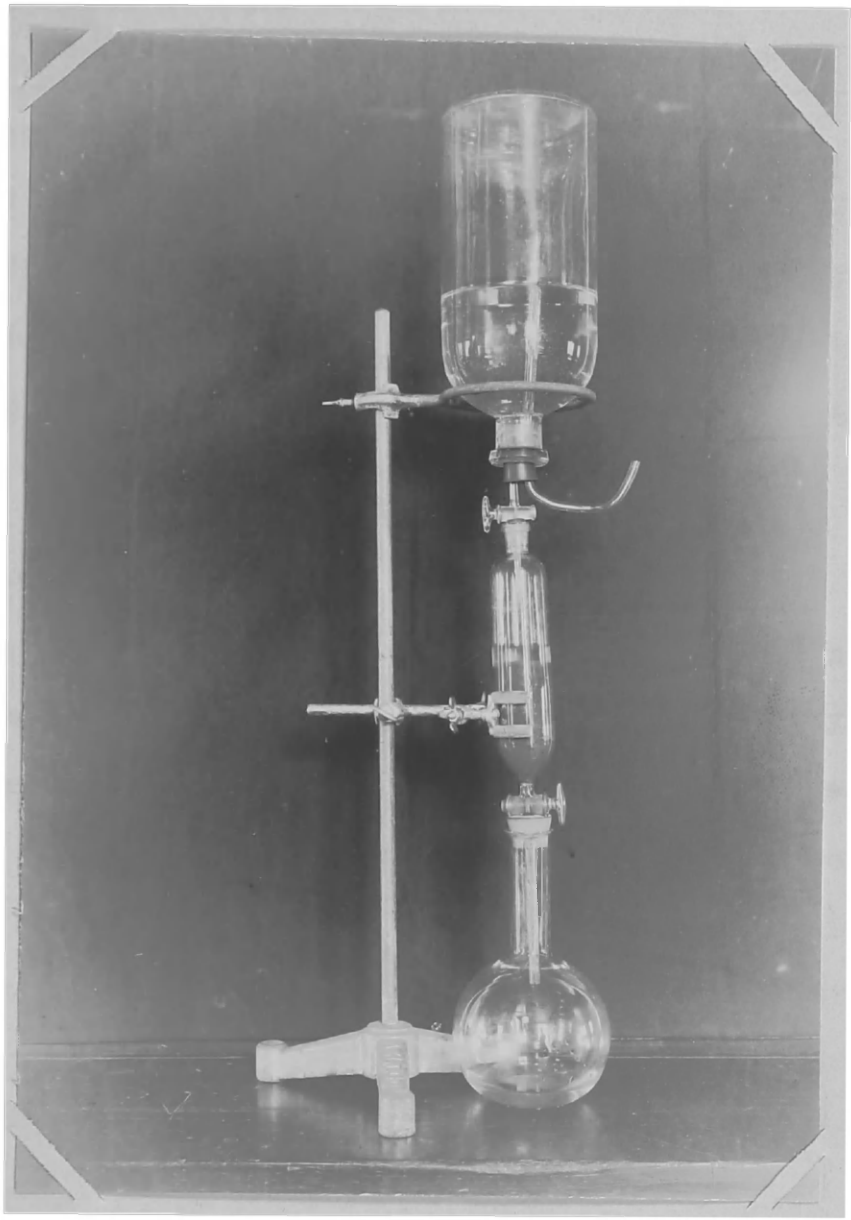

Fig. 5. Leaching apparatus used for leaching soil with solutions of potassium salts and 0.05N HCl.

it was found possible to maintain about an inch of "head" over the soil and thus prevent channeling. Difficulty was encountered in regulating the flow at a slow rate, but with care the rate was so reduced as to permit 2 liters of solution to pass through in about 60 hours. The extraction funnel was charged each time with 200 grams of air-dry Norfolk sandy loam which had been passed through a 20-mesh sieve. The apparatus was set up in the laboratory where a temperature of about 22°C. obtained throughout the experiments.

Samples of the soil were leached with solutions of different C.P. potassium salts and the potassium content in each leaching was determined gravimetrically (43). The hydrogen-ion concentration of each leaching was determined electrometrically using a Hildebrand bubbling electrode. Conductivity measurements were made at 23°C. with a Kohlrausch bridge according to the method described by Findlay (9). Immediately after each leaching was completed, one liter of 0.05 N. HCl was passed through the soil and the leachings collected in 500 c.c. fractions. This procedure was similar to that described by Gedroiz (13) in determining the replaceable bases in soil. The same determinations were made on each fractional leaching as were made on the leachings from the salt solutions. The results from these determinations are shown in Table 14.

It will be seen from Table 14 that Norfolk sandy loam seems to be capable of adsorbing potassium far in excesses of the

Table 14.

Adsorption of Potassium from 1 Liter of Solution by 200 grams Soil.

Solution	CC's leached	CC's retained	Grams K added	Grams K in leaching	Grams K adsorbed	Weight K adsorbed per gr. soil	pH leaching	Conductivity of ($\times 10^{-4}$) leaching
0.1 N KCl	940	60	3.9	0.9063	2.9937	0.0149	7.2	108.11
0.1 N K_2SO_4	945	55	3.9	0.5627	3.3373	0.0166	7.0	180.97
0.1 N KCl plus NaCl Ratio (33:40)	945	55	3.9	0.5594	3.3406	0.0167	6.8	249.51

amount which is normally applied in a fertilizer treatment for potatoes. The results show that potassium was adsorbed to a slightly greater degree from potassium sulphate than from potassium chloride. When potassium chloride and sodium chloride were mixed in the proportions found in manure salts (33:40), about the same amount of potassium was adsorbed per gram of soil as in the case where potassium sulphate was used, and slightly more than in the case where potassium chloride was used alone. These results indicate that undoubtedly the sodium chloride in manure salts had little effect on the adsorption of potassium from potassium chloride in this soil. It would seem unlikely, then, that the potassium applied in manure salts under field conditions should penetrate to a greater depth in the soil and be removed from the feeding area of the potato plant. In this connection, the lower yields of potatoes reported in Tables 6 and 12 where manure salts were compared with muriate and sulphate of potash, cannot be explained on this basis.

The reactions of the leachings are interesting since in only one case, where sodium chloride was added to a solution of potassium chloride, was the hydrogen-ion concentration increased. This increased acidity may have been caused by a selective adsorption of the Cations (7). In Table 15 is shown the replacement of potassium in treated and untreated soil by a solution of 0.05 N. HCl.

Table 15.

Replacement of Adsorbed K in 200 Grams Soil Previously Treated with 0.1 N KCl using 0.05 N HCl.

Treatment	CC's leached.	Grams K leached	Grams K Adsorbed	Percent adsorbed K replaceable	Conductivity x 10^{-4}	pH
1st leaching	500	0.0720	2.9937	2.45	57.00	2.5
2nd leaching	500	trace	trace	trace	74.33	1.8

Replacement of Adsorbed K in 200 Grams Soil Previously Treated with 0.1 N K_2SO_4 using 0.05 N HCl.

1st leaching	500	0.05785	3.3373	1.73	43.77	2.7
2nd leaching	500	0.01612	3.27945	0.41	46.44	2.0

Replacement of Adsorbed K in 200 Grams Soil Previously Treated with 0.1 N KCl plus NaCl using 0.05 N HCl.

1st leaching	500	0.0689	3.3406	2.06	53.75	2.8
2nd leaching	500	trace	trace	trace	43.14	2.1

Replacement of Adsorbed K in 200 Grams Air-Dry Soil Using 0.05 N HCl.

1st leaching	500	trace	--	--	27.63	2.8
2nd leaching	450	trace	--	--	56.54	2.0

An inspection of Table 15 reveals the fact that the potassium adsorbed by the soil from a solution of potassium sulphate is held more tightly than potassium adsorbed from a solution of potassium chloride. When potassium sulphate was used, only 1.73% of the adsorbed potassium could be replaced at the first leaching. At the second leaching, 0.41% could still be replaced. However, for the potassium chloride solution, 2.45% of the adsorbed potassium could be replaced at the first leaching and only a trace at the second leaching. The presence of sodium chloride apparently did not alter the amount of potassium replaceable.

It may also be seen from Table 15 that only a trace of potassium was replaced when untreated air-dry soil was leached with a liter of 0.05 N. HCl. For this reason no allowance was made for the replaceable potassium of the untreated soil, in calculating the results in Tables 14 and 15. For all treatments, the amount of potassium adsorbed by the soil was so large in comparison to that which was replaceable in the untreated soil, that the latter was negligible.

An examination of the conductivity measurements shows that there was an increase in conductivity between the first and second leachings in every case but one. Further, it will be noted that in each case this increase was characterized by an increase in acidity as shown by the pH values. Evidently some of the hydrogen-ions in the first HCl leaching were used in replacing the adsorbed bases, as indicated by the percentage of potassium replaced in the first and second leachings. At the second leaching, more of the hydrogen-ions passed through the soil and therefore the increased conductivity in this case was undoubtedly due to the fast-moving hydrogen-ions rather than to an increase in salt content. The pH of the 0.05 N. HCl. solutions used, ranged from pH 1.6 to 1.8, the solutions being made only to approximate strength.

In an experiment of this kind it is not to be expected that equilibrium was reached between the soil and the leaching solutions. The duration of the leachings was entirely too short to permit equilibrium to be accomplished. Moreover, under field conditions it is very unlikely that equilibrium would ever be reached on account of the dynamic nature of the soil and the soil solution. It is because of this fact that it seemed justifiable to carry the problem into the laboratory under somewhat controlled conditions, and to use quantities of potassium salts considerably greater than those actually used in the field. Even at best, such experiments can only serve to indicate in a general way the adsorption that may be expected under field conditions.

Effect of Potassium Materials on Nitrification

The small yields of potatoes that have been obtained where a fertilizer deficient in nitrogen was used in the field experiments, establishes beyond a doubt the fact that nitrogen is a limiting factor in potato production on Norfolk Sandy loam soil. Not only is it evident that the fertilizer used must be high in nitrogen, but it also seems necessary to supply part of the nitrogen from organic materials, in order to get the highest yields. Consequently, a study of the efficiency of nitrogenous fertilizers, in this case, may be extended to include the materials supplying phosphorus and potassium, insofar as they may affect the rate and accumulation of nitrates in the soil.

In order to study the relative effects of potassium chloride, potassium sulphate, and manure salts on the rate and accumulation of nitrates resulting from the nitrification of sulphate of ammonia, dried ground fish, and packing house tankage in Norfolk sandy loam, a rather extensive laboratory experiment was made.

Methods and Plan of Experiment.

Commercial fertilizer materials were used to supply the nitrogen and potassium in the fertilizer mixtures; and for the phosphorus, 16% superphosphate was used, making no allowance for the phosphorus contained in the organic materials. Analyses of the nitrogen and potassium materials are given in Table 16.

The experiment was divided into three series according to the source of nitrogen used in the fertilizer mixture. In

Table 16.

Analyses of Fertilizer Materials Used.

	Percent NH_3	Percent K_2O	Percent NaCl
Sulphate of Ammonia	25.0		
Packing House Tankage	7.2		
Dried Ground Fish	11.8		
Potassium Chloride		50.2	14.0
Potassium Sulphate		49.7	1.0
Manure Salts		20.8	43.4

Series I, dried ground fish was used as the only source of nitrogen supplying the equivalent of seven units of ammonia. In the same manner, packing house tankage was used in Series II and sulphate of ammonia in Series III. In each series, equivalent amounts of potassium were supplied from potassium chloride, potassium sulphate, and manure salts at three rates corresponding to 5, 8, and 10 units of potash. Six units of phosphoric acid were supplied in each case from superphosphate. By this arrangement, the source and amount of nitrogen and phosphorus remained constant throughout each series, and potassium varied within each series both as to source and amount.

The fertilizer mixtures were thoroughly mixed with surface soil taken from the Snow Hill Experimental Plots at the rate of 6 grams per 2000 grams of air-dry soil. This rate of treatment amounted to 345.9 mgm. of nitrogen and corresponded to a row application of 2000 pounds of fertilizer per acre analyzing 7% ammonia. After each treatment was made, the soil was placed in half-gallon glazed pots and removed to the greenhouse. Sufficient distilled water was added to bring the moisture content to 60% of saturation. The combined weight of soil and pots were recorded and constant moisture conditions were maintained by additions of distilled water to weight at frequent intervals. The temperature was recorded in the greenhouse during the experiment but was not controlled.

Immediately after moisture was added, a 70-gram sample of the soil for the entire depth in each pot was taken with a brass tube. These samples were dried over night at 55°C. to check bacterial action. The nitrate content of each sample was determined by the phenoldisulphonic acid method as modified by Harper (17). This method was used throughout for all nitrate determinations, 50 grams of soil being extracted with 250 c.c. of distilled water for the determination. The hydrogen-ion concentration was determined electrometrically as in the previous experiments. Samples were taken every 20 days for 100 days, and both nitrate and hydrogen-ion determinations were made on each sample. At the end of the experiment, conductivity measurements were made on each sample at 21°C on a 1-5 extraction of each soil after shaking for two hours. The total nitrates in parts per million of air-dry soil, the pH for each sample and the conductivity results at the final period, are shown for each series in Tables 17, 18, and 19.

Discussion of Results

Series I.

An examination of Table 17 shows a marked reduction in the rate of nitrification of dried ground fish in every case, up to 40 days, where potassium materials were added. At these periods, the nitrification of fish was greatest where potassium sulphate was applied in the lowest concentration, and smallest where manure salts were applied in the highest concentration.

Table 17.

Effect of Different Amounts and Different Sources of Potassium on Nitrification of Dried Ground Fish in a Complete Fertilizer.

Parts per million nitrate-nitrogen in air-dry soil

Source of Potassium	Equivalent Analysis	Dec. 15 0 Da.	pH	Jan. 4 20 da.	pH	Jan. 24 40 da.	pH	Feb. 13 60 da.	pH	Mar. 4 80 da.	pH	Mar. 24 100 da.	pH	Co duc iv ty 10
Potassium Chloride	7-6-5	3.5*	6.5	2.1	6.7	50.4	6.2	140.8	5.2	109.0	5.3	109.6	4.9	4.[illegible]
Potassium Chloride	7-6-8	3.5	6.6	3.6	6.7	34.7	6.3	126.6	5.3	113.2	5.1	133.3	5.0	5.[illegible]
Potassium Chloride	7-6-10	3.5	6.5	3.4	6.5	13.2	6.2	89.8	5.6	115.4	5.2	109.9	5.0	6.[illegible]
Potassium Sulphate	7-6-5	3.5	6.5	3.7	6.7	71.4	6.1	125.3	5.3	123.5	5.1	134.7	5.0	4.[illegible]
Potassium Sulphate	7-6-8	3.5	6.8	3.5	6.8	60.8	5.9	116.3	5.5	114.0	5.1	99.2	5.0	4.[illegible]
Potassium Sulphate	7-6-10	3.5	6.6	3.9	6.6	60.3	5.8	124.5	5.2	132.1	5.1	148.1	4.9	4.[illegible]
Manure Salts	7-6-5	3.5	6.4	3.3	6.7	33.6	6.0	127.2	5.3	106.8	5.1	133.3	5.0	4.[illegible]
Manure Salts	7-6-8	3.5	6.5	3.5	6.7	29.7	6.3	81.1	5.5	113.2	5.0	105.8	5.0	7.[illegible]
Manure Salts	7-6-10	3.5	6.0	3.5	6.8	12.2	6.1	67.7	5.6	88.2	5.3	144.9	4.9	8.2
Control	7-6-0	3.5	6.7	7.3	6.3	88.8	5.9	109.9	5.3	72.2	5.2	100.0	4.5	4.1
Mean Temperature				45.7°F		48.8°F		49.6°F		55.5°F		52.9°F		

*The average for all the determinations is given.

In almost every case, the relative nitrate accumulation up to 60 days seemed to decrease as the rate of potassium salts was increased. After 60 days, the rate of nitrification decreased where the most nitrates had accumulated and increased where a smaller amount of nitrates had accumulated. In some cases, an actual loss of nitrates took place, probably due to the utilization of nitrates by the nitrate assimilating organisms. As a consequence, the total nitrate accumulation at the end of the experiment was about the same in almost every case. A comparison of the reduction in rates of nitrification, as affected by the three potassium materials used, shows manure salts to have the greatest effect, followed by potassium chloride and potassium sulphate in the order named.

The hydrogen-ion concentration did not seem to be a controlling factor in the nitrification of dried ground fish, even though there was a gradual increase in acidity throughout the experiment. The pH was remarkably constant for any one sampling regardless of the source of potassium used. It may be noticed from the data in Table 17 that the pH of the control was approximately the same as that of the potassium-treated soils at every sampling. This would indicate that the increase in acidity was caused by the action of microorganisms and not by the addition of potassium salts.

The conductivity measurements serve to indicate the relative salt content of the various soils. From Table 17 it may be seen that there was a gradual increase in conductivity at the end of the experiment which corresponded to the amounts of potassium materials applied at the beginning. The conductivity was especially high in the case of manure salts, indicating a high salt content where this material was used. It may also be noted from Table 17 that the accumulation of nitrates, after 60 days, was inversely proportional to the conductivity of the samples at the end of the experiment.

Series II

As shown in Table 18 the nitrification of packing house tankage was very much similar to that obtained in Series I where dried ground fish was used as the source of nitrogen. However, an examination of the data given in Table 18 reveals some rather striking differences where manure salts were used. The rate of nitrification and the accumulation of nitrates in this case were decidedly less than in Series I. Decreased nitrification with increasing applications of potassium was noticeable for all three potassium materials after 80 days, and when manure salts were used, a noticeable decrease was obtained even at the end of the experiment. In this series, as in Series I, potassium sulphate, and to a lesser degree potassium chloride, at the lowest concentrations, showed an increased rate of nitrification over that obtained in the control.

Table 18.

Effect of Different Amounts and Different Sources of Potassium on Nitrification of Packing House Tankage in a Complete Fertilizer.

Parts per million nitrate-nitrogen in air-dry soil

Source of Potassium	Equivalent Analysis	Dec. 15 0 da.*	pH	Jan. 4 20 da.	pH	Jan. 24 40 da.	pH	Feb. 13 60 da.	pH	Mar. 4 80 da.	pH	Mar. 24 100 da.	pH	Co du iv ty 10
Potassium Chloride	7-6-5	4.1	6.1	11.4	6.4	46.7	5.6	72.6	5.3	114.0	4.9	105.0	4.8	5.
Potassium Chloride	7-6-8	4.1	6.0	11.3	6.2	40.4	5.5	66.2	5.0	69.3	5.0	120.5	4.8	6.
Potassium Chloride	7-6-10	4.1	6.5	11.4	6.0	28.5	5.6	44.7	5.2	43.1	5.1	128.7	4.8	7.
Potassium Sulphate	7-6-5	4.1	6.0	16.2	6.4	43.2	5.3	109.1	4.9	101.0	4.8	143.4	4.6	6.
Potassium Sulphate	7-6-8	4.1	6.4	16.9	5.9	55.5	5.0	101.7	4.8	86.9	4.7	98.0	4.6	6.
Potassium Sulphate	7-6-10	4.1	6.4	17.5	5.7	36.4	5.7	81.0	5.4	79.5	5.1	117.6	4.7	6.
Manure Salts	7-6-5	4.1	6.0	11.0	6.4	20.2	5.7	107.1	5.0	76.9	5.1	76.5	4.9	7.
Manure Salts	7-6-8	4.1	6.2	10.1	5.9	27.3	5.2	63.3	5.4	64.2	5.0	75.0	4.8	9.
Manure Salts	7-6-10	4.1	6.0	8.6	6.0	20.5	5.9	27.0	5.2	56.3	5.4	54.0	4.9	9.
Control	7-6-0	4.1	6.6	21.2	5.9	40.7	5.6	86.7	4.7	110.7	4.5	95.2	4.9	5.

*The average for all determinations is given.

No significant variations occurred in the hydrogen-ion concentrations of the successive samples in Series II. The increase in acidity was gradual as in Series I but the final pH was lower in most cases.

In all cases but two, the conductivity measurements after 100 days showed a corresponding increase in conductivity with the rate of potassium applied at the beginning. The conductivity was highest and the accumulation of nitrates lowest, where manure salts were used. The accumulation of nitrates, up to 80 days, in every case was noticeably less as the conductivity increased.

Series III

The data obtained from the nitrification of sulphate of ammonia as affected by the various potassium materials are shown in Table 19. The results show that both the rate of nitrification and the accumulation of nitrates were greater where potassium sulphate was used at all three concentrations, than where potassium chloride was used. A slight stimulating effect in the nitrification of sulphate of ammonia was evidenced by potassium sulphate after 20 and 40 days. In every case both the rate and accumulation of nitrates for the control were greater than where manure salts were used. The highest application of manure salts was very toxic to nitrification.

The initial and final pH of the samples in this series were, in the majority of cases, lower than found in Series I and

Table 19.

Effect of Different Amounts and Different Sources of Potassium on Nitrification of Sulphate of Ammonia in a Complete Fertilizer.

Parts per million nitrate-nitrogen in air-dry soil

Source of Potassium	Equivalent Analysis	Dec. 15 0 da.	pH	Jan. 4 20 da.	pH	Jan. 24 40 Da.	pH	Feb. 13 60 da.	pH	Mar. 4 80 da.	pH	Mar. 24 100 da.	pH
Potassium Chloride	7-6-5	3.2*	6.0	14.0	5.4	27.1	5.7	35.7	5.0	71.6	5.2	89.5	4.7
Potassium Chloride	7-6-8	3.2	6.0	10.2	5.7	28.0	5.6	46.5	5.2	70.6	4.9	80.9	4.8
Potassium Chloride	7-6-10	3.2	6.2	14.5	5.4	23.4	5.7	40.9	5.1	37.3	5.3	58.8	5.0
Potassium Sulphate	7-6-5	3.2	5.9	19.2	5.6	47.0	5.5	46.9	5.2	66.7	4.9	105.3	4.5
Potassium Sulphate	7-6-8	3.2	5.9	11.6	5.5	35.6	5.4	51.0	5.0	66.5	5.0	84.5	4.5
Potassium Sulphate	7-6-10	3.2	6.4	19.2	5.6	40.8	5.4	61.5	4.8	84.0	4.7	101.7	4.7
Manure Salts	7-6-5	3.2	6.1	13.0	5.3	30.6	5.3	54.0	5.0	62.2	5.0	63.8	4.8
Manure Salts	7-6-8	3.2	5.6	9.4	5.7	22.4	5.7	36.7	5.2	38.1	5.0	59.4	5.1
Manure Salts	7-6-10	3.2	6.3	9.0	5.6	18.9	5.6	33.5	5.1	34.4	5.4	49.0	4.7
Control	7-6-0	3.2	6.2	14.4	5.4	37.0	5.4	68.8	4.9	92.8	4.7	72.3	4.6

*The average for all determinations is given.

II. This increased acidity was undoubtedly the result of acid formation during the nitrification of the sulphate of ammonia as pointed out by Waksman (50).

In Series III the conductivity measurements again increased as the nitrate accumulation decreased. This was especially noticeable where manure salts were used. Nitrate accumulation was lowest for the entire series in every case where equivalent amounts of potassium were supplied by manure salts.

General Discussion of Nitrification Results.

From the results obtained in Series I, II, and III it is evident that manure salts inhibited the nitrification of dried ground fish, packing house tankage, and sulphate of ammonia, when used as the only source of potassium in complete fertilizers containing 5, 8, and 10 units of potash. The toxic effect of the manure salts was more evident with increasing amounts, but even at the lowest rate, the nitrification of the nitrogenous materials with few exceptions, was less than where potassium chloride or potassium sulphate replaced this material in the mixture. It would seem from the conductivity measurements that this toxic effect was caused merely by an increase in total salt content. However, a careful examination of the data will show that this is not the case. In several instances nitrification was less where manure salts were used, than where potassium chloride or potassium sulphate was used, yet the total salt content of the soil containing manure salts, as indicated by conductivity, was lower than that of the soil containing the other potassium materials. It would seem that the toxic effect of manure salts is caused by the presence of sodium chloride. In this connection, Greaves (16) showed that sodium chloride became toxic to nitrification in amounts in the soil exceeding 460 p.p.m. of sodium He attributed the toxic effect of sodium chloride to a physiological influence which it exerts upon the protoplasm of the organisms and not to a direct osmotic effect. Other workers, Lipman (26), Patterson and Scott (33), Brown and Hitchcock (6), Lipman (24) Gibbs, Batchelor, and Magnuson (15) found that sodium chloride in concentrations of from 0.1 to 0.2% was distinctly toxic to nitrifying organisms.

According to the analysis of manure salts given in Table 16, this material contained 43.0% sodium chloride. At the three rates used in this experiment, this would mean that sodium was applied with manure salts at the rate of 305, 500, and 610 parts per million. It is evident that the toxic limits for nitrification in the presence of sodium according to Greaves (16) was exceeded in every case where manure salts were used. The fact that small amounts of sodium chloride have been found to have a stimulating effect upon nitrification (16), may account in part for the general increase in nitrate accumulations where potassium chloride and potassium sulphate were used. It may be seen from Table 16 that both these materials contain a relatively small amount of sodium chloride. It is also possible that nitrification may have been stimulated somewhat by the potassium added, as it will be seen from the analysis in Table 1, that the soil was extremely deficient in this element.

From the foregoing experiments it is evident that the nitrogen and potassium fertilizer problems concerning the production of potatoes on Norfolk sandy loam are not distinctly separate. The experimental data presented show that the material used as a source of potassium may affect nitrification in the soil and thus influence the rate and accumulation of nitrates from nitrogenous materials. Manure salts, because of its large sodium chloride content, appears to be very toxic to nitrifying organisms when used in large amounts. The extent to which this material will reduce nitrification under field conditions is probably dependent upon the rate of application, amount of rainfall, and the soil. However, in field trials with potatoes on Norfolk sandy loam, it has not proved as satisfactory as either muriate of sulphate of potash.

General Summary of Results.

Early Potatoes.

A comparison of different forms of nitrogen in a 7-6-5 fertilizer mixture used for early potatoes indicated the value of deriving a part of the nitrogen from organic sources.

Leunasalpeter compared very favorably with nitrate of soda and sulphate of ammonia as a source of inorganic nitrogen in the fertilizer mixture but the mechanical condition of the mixture was extremely bad.

Potato yields obtained on a sand hill were increased where a green manure cover crop of rye and vetch was grown the preceeding winter and early spring.

The yields of potatoes were lowered when the soluble mineral nitrogen portion of the fertilizer mixture, usually applied at planting time, was omitted and its application deferred until the first cultivation of the crop.

In every case plots receiving potash gave higher average yields of potatoes in comparison to the average yields produced on the no-potash plots. A comparison of the potash materials used showed muriate, first; sulphate, second; and manure salts, third, from the standpoint of yields produced.

Double strength fertilizers applied at half the usual rate compared favorably with the regular 7-6-5 mixtures applied at 2000 pounds per acre, with respect to yields of early potatoes produced.

Sweet Potatoes.

From a comparison of different forms of nitrogen in a 3-8-8 fertilizer used for sweet potatoes, the soluble materials such as urea, nitrate of soda, and sulphate of ammonia produced the highest average yields of prime potatoes. Of the inorganic-organic combinations the 60%-40% ratio gave the highest average yield of prime potatoes. It was suggested that a soluble nitrogen material in the fertilizer mixture helped to establish the sweet potato sprout in the field.

The results of one year's work with Leunasalpeter indicated that it was a very suitable nitrogen material for sweet potatoes, when used in conjunction with organics. In this respect, it compared very favorably with nitrate of soda and sulphate of ammonia.

A green manure cover crop of rye and vetch, used in the rotation in conjunction with the regular fertilizer application, gave significant increases in yields of potatoes.

The yields of prime potatoes were larger in every case where potash was used, as compared with the yields obtained where treatments were applied containing no potash. The increases for all the potash materials used were not uniform. Sulphate of potash gave the highest yields, followed by muriate of potash and manure salts, in the order named.

No injurious effects were noticeable when a double strength fertilizer was applied at the rate of 750 pounds per acre for sweet potatoes. It was suggested, however, that a dry season may bring about very different results with concentrated fertilizer mixtures.

Adsorption and Nitrification.

Samples of Norfolk sandy loam soil adsorbed considerable amounts of potassium when leached with 0.1 N. solutions of potassium salts.

The addition of sodium chloride to a solution of potassium chloride, in the proportions found in manure salts, did not reduce the amount of potassium adsorbed by the soil.

Potassium sulphate was adsorbed to a slightly greater degree than potassium chloride.

The potassium adsorbed from a solution of potassium chloride was replaced by dilute acid more rapidly than the potassium adsorbed from a potassium sulphate solution. The addition of sodium chloride did not affect the replacement of the potassium adsorbed from potassium chloride.

The nitrification of dried ground fish, packing house tankage, and sulphate of ammonia was inhibited when manure salts were used as the only source of potassium in a complete fertilizer mixture.

A slight stimulating effect on nitrification was obtained where potassium sulphate was used.

In general nitrification decreased as the concentration of the potassium materials increased but the decrease was greatest where manure salts were used.

Conclusions

1. A portion of the ammonia in the fertilizer mixture for early potatoes grown on Norfolk sandy loam should be supplied by organics. A larger portion of ammonia should be supplied from inorganic than organic materials.

2. A green manure cover crop of rye and vetch used in the regular fertility program on light sandy soils where commercial fertilizers are applied, will help to conserve the fertilizer residues and to increase yields.

3. One year's results show that applications of potash are needed to obtain maximum yields of early potatoes on this soil and that either muriate or sulphate of potash is preferable to manure salts when applied on the basis of equivalent amounts of potash.

4. Sweet potato fertilizers for Norfolk sandy loam should contain a larger percentage of nitrogen from soluble materials than from the more slowly soluble organic materials.

5. From the first year's results with potash materials, sulphate of potash appeared to be a more suitable material in a complete fertilizer mixture for sweet potatoes, than either muriate of potash or manure salts.

6. Norfolk sandy loam exhibited an appreciable adsorptive power for potassium, so that losses of potassium by leaching

were probably small.

7. Large applications of manure salts inhibited the nitrification of organic materials in the soil and the toxic action was probably indirectly responsible for the decreased yields of potatoes that were obtained where this potash material was used.

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FIELD PLOTS

MARYLAND AGRICULTURAL EXPERIMENT STATION

JEROME JOHNSON FARM AT

SNOW HILL, MD.

FIELD PLAN BY G.W.C. HOUGHLAND

FEBRUARY - 1927.

RANGE B.